

AN EVALUATION OF SMALL UPLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

- I. GENERAL APPROACH
- II. SUMMARY OF FINDINGS
 - Effect of the System on Floods
 - Flood reduction Benefits
 - Recreational Benefits
 - Benefits in the Form of Increased Fish and Game Production
 - Other Benefits
 - Cost-Benefit Relations
- III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS
 - The System to be Evaluated
 - Notation
 - General Physical, Hydrologic, and Hydraulic Relationships
 - Functional Design of Each Reservoir
- IV. EVALUATION OF FLOOD REDUCTIONS BY THE RESERVOIR SYSTEM
 - Development of Tributary Hydrographs
 - Hydraulic Equivalent Reach Cross-Sections
 - Routing Flood Waves Through Stream Reaches
 - Reach Hydrographs and Reservoir Reduction Trends
 - Modification of Flood Reductions by Reservoirs for Average Runoff Conditions
- V. DETERMINATION OF AVERAGE ANNUAL FLOOD REDUCTION BENEFITS
- VI. RECREATIONAL BENEFITS
- VII. BENEFITS IN THE FORM OF INCREASED FISH AND GAME PRODUCTION
- VIII. OTHER BENEFITS
- IX. PRELIMINARY COST ESTIMATES
- X. TABLES
- XI. FIGURES
- XII. BIBLIOGRAPHY

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This investigation should be considered as one of a preliminary nature. The design and placement of reservoirs on the basin is purely functional and its use is intended for estimating purposes only. In other words, data as given relative to any one specific reservoir may vary appreciably from the actual conditions present on the site, and are simply the most probable estimate that could be made from materials at hand without an actual visitation to the site. The decision to install a system of reservoirs of the type considered would necessitate the specific location of reservoirs and the determination of detailed physical information on each site.

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There are two fundamental principles involved in flood control. First, the amount of runoff may be decreased, and second, the timing of runoff to, or within, the stream channel system may be controlled to reduce peaks of flood flow. Land programs decrease the amount of flood runoff by the abstraction of rainfall producing floods. Large storage reservoirs may be used to abstract all or a portion of flood runoff from specific land areas. Retarding basins may be used to modify the timing of runoff from specific land areas into larger channel systems. The channel systems may also be treated to govern the timing and to modify the flood waves passing through them.

The initiation of land programs to abstract flow from floods and to control excessive erosion and siltation is basic to the successful application of other flood control devices. In addition to the benefits secured from the application of a land program further protection from floods will in most cases be needed. The location and type of flood damages should govern the choice of additional measures. Where the damages in small basins are primarily agricultural, small retarding basins located in the headwaters may give the desired protection. Larger structures will be necessary to give more absolute protection to concentrations of large damageable values.

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I. GENERAL APPROACH

A total of 253 small reservoirs were theoretically placed on the Meramec Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 56 tributary watersheds of the Meramec Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin.

The modification of average flood flows by the reservoirs was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be credited.

1. GENERAL APPROACH

A total of 253 small reservoirs were theoretically placed on the Laramie Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 50 tributary watersheds of the Laramie Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin. The modification of average flood flows by the reservoirs

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credited.

The type and distribution of water areas, or conservation pools, common to installation of the small reservoirs is such that they create a new resource for recreation and the production of wildlife. The addition of these benefits to those determined for flood control comprises the estimated value of the reservoir system.

Estimates of the cost of installation of the reservoirs, their maintenance, and the acquisition and control of properties necessary for their placement and management constitute the original and continuing cost of the benefits to be attained. The relation of costs to benefits determines the economic feasibility of the system.

In the general organization of this report the basic tables and figures have been appended in the order in which they are mentioned in the body of the report.

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II. SUMMARY OF FINDINGS

Effect of the System on Floods

The location of small reservoirs, as an average, produces flood reductions of approximately 35 percent on the headwaters tributaries which drain areas from 50 to 125 square miles. The magnitude of this reduction becomes progressively less as the flood waves proceed to the lower portions of the basin. Thus, the estimated flood reduction on the main stem of the Meramec is approximately 20 percent.

Upon routing and combining flood waves on each of the Bourbeuse, Big, and Meramec Rivers, it became apparent that small retarding basins should not be placed on the lower portions of each watershed. These lower portions of each watershed are relatively narrow and, in the normal course of events, contribute but little to the flood peaks which tend to originate at points farther up the basin. Flood producing storms tend to be of fairly wide scope on the basin, and runoff from the lower reaches normally moves out of the lower areas before the main peak of the flood arrives. To retard this runoff with small reservoirs will, in general, cause its direct addition to the main crest of the flood wave from above. Reservoirs below mile 31.6 on the Bourbeuse River, 107.5 on the Meramec River, and 22.6 on the Big River were, therefore, eliminated from the evaluation. This leaves a total of 198 reservoirs upon which all flood reductions are subsequently based. Recreation lakes without retarding features could, however, be built in these lower portions of the basin near the St. Louis area without conflict to flood control.

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Wide variation in the reductions which the reservoirs will effect on specific floods are anticipated. Maximum reductions will be made on intense runoff that comes as a single peak flood when the entire flood storage capacity of the reservoirs is available. When the reservoirs are retaining runoff from previous storms and are in the process of discharging it at the time of a subsequent storm, the peak runoff from this second storm may upon occasion be greater than it would be without the reservoir system. Fortunately, this event will be of infrequent occurrence and is most likely to take place in the early spring or late fall months during the dormant seasons.

The type of control common to a system of small reservoirs is well adapted to a basin in which the flood damages are predominantly agricultural. Since approximately 75 percent of the existing flood damages in the Meramec Basin are comprised of those to farm crops and lands, and approximately 80 percent of them occur during the growing season, May through September, the control secured by small retarding devices is particularly effective.

The storms that produce flood damage on the Meramec Basin vary in duration from several hours to a few days. On larger watersheds, such as the Mississippi River Basin, the damaging floods result from protracted storms of wide scope where runoff accumulates in the river drainage system over a much longer period. Retarding devices such as those considered on the Meramec Basin, wherein runoff is temporarily detained for only a few days, will have negligible effect on Mississippi River floods.

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such as those considered on the Tennessee Basin, wherein runoff is tem-

porarily detained for only a few days, will have negligible effect on

Mississippi River floods.

Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$516,670 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,000, or 55 percent of the total now existing on the basin.

In applying increasingly rigid control measures to eliminate flood damages, the law of diminishing returns is operative. Thus, a greater benefit is secured by the first unit reduction than for succeeding equal unit reductions in floods. Since considerable time would necessarily elapse before the land program could be installed and become fully effective, the benefits directly ascribable to the reservoirs were evaluated by considering the land program to be 50 percent effective and eliminating farm ponds from the calculation. This method appears to be equitable and yields a flood control benefit of \$200,050 annually which is directly attributable to the reservoir system.

Of the \$200,050 annual benefit assigned to the small reservoirs, \$111,150 is obtained on the basin above the location of land areas inundated by the proposed construction of three multiple-purpose dams by the War Department.

Flood Reduction Benefits

Flood damages on the western basin are estimated at \$210,000 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$100,000. When the system of 108 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$280,000, or 55 percent of the total now existing on the basin.

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by the War Department.

Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extention of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$124,510 per year. The amount of this increase is equivalent to \$628.84 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

The breakdown of increased fish and game production is as follows:

Fish	394,098 pounds @ \$0.25	\$98,524.00
Fur		
Muskrats . . .	3,059 pelts @ 1.50 . .	\$4,588.50
Mink	620 pelts @ 8.00 . .	4,960.00
Beaver	175 pelts @ 25.00 . .	4,375.00
Raccoon . . .	75 pelts @ 3.50 . .	262.50
		<u>14,186.00</u>
Waterfowl	23,600 items @ 0.50	<u>11,800.00</u>
Total		\$124,510.00

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general guide for reservoir placement:

1. Reservoirs are to be placed above a point where permanent stream flow occurs.
2. The drainage area to an individual reservoir is to average less than 10 square miles.
3. Sufficient coverage of the land area should be made to eliminate ordinary flood damage throughout the basin.
4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

Regarding a specific reservoir, the following points were assumed to be desirable:

1. A permanent or conservation pool is to be maintained for utility and recreational purposes.
2. Temporary flood storage is to be provided above the permanent pool level.
3. Temporary flood storage capacity should be provided for 2 to 3 inches of surface runoff from the drainage area.
4. The depth of temporary flood storage above the permanent pool should not exceed 10 feet.
5. Temporary flood storage will be released without manual control.
6. Temporary flood storage is to be depleted at a rate which will cause a minimum of stream flow below the reservoir without destroying desirable vegetation, or resulting in loss of recreational value on the area adjacent to the permanent conservation pool.

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There are included in the report graphs and maps as they are needed to illustrate the various phases of the study. The report is organized so that the reader can follow the progress of the study from the beginning to the end. The report is divided into four main parts: the first part contains the general introduction and the statement of the problem; the second part contains the description of the study area and the methods used; the third part contains the results of the study; and the fourth part contains the conclusions and recommendations.

Continued.

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Wide variation in the reductions which the reservoirs will effect on specific floods are anticipated. Maximum reductions will be made on intense runoff that comes as a single peak flood when the entire flood storage capacity of the reservoirs is available. When the reservoirs are retaining runoff from previous storms and are in the process of discharging it at the time of a subsequent storm, the peak runoff from this second storm may upon occasion be greater than it would be without the reservoir system. Fortunately, this event will be of infrequent occurrence and is most likely to take place in the early spring or late fall months during the dormant seasons.

The type of control common to a system of small reservoirs is well adapted to a basin in which the flood damages are predominantly agricultural. Since approximately 75 percent of the existing flood damages in the Meramec Basin are comprised of those to farm crops and lands, and approximately 80 percent of them occur during the growing season, May through September, the control secured by small retarding devices is particularly effective.

The storms that produce flood damage on the Meramec Basin vary in duration from several hours to a few days. On larger watersheds, such as the Mississippi River Basin, the damaging floods result from protracted storms of wide scope where runoff accumulates in the river drainage system over a much longer period. Retarding devices such as those considered on the Meramec Basin, wherein runoff is temporarily detained for only a few days, will have negligible effect on Mississippi River floods.

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Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$516,670 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,000, or 55 percent of the total now existing on the basin.

In applying increasingly rigid control measures to eliminate flood damages, the law of diminishing returns is operative. Thus, a greater benefit is secured by the first unit reduction than for succeeding equal unit reductions in floods. Since considerable time would necessarily elapse before the land program could be installed and become fully effective, the benefits directly ascribable to the reservoirs were evaluated by considering the land program to be 50 percent effective and eliminating farm ponds from the calculation. This method appears to be equitable and yields a flood control benefit of \$200,050 annually which is directly attributable to the reservoir system.

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Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extention of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$124,510 per year. The amount of this increase is equivalent to \$628.84 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

The breakdown of increased fish and game production is as follows:

Fish 394,098 pounds @ \$0.25 \$98,524.00

Fur

Muskrats . . 3,059 pelts @ 1.50 . . \$4,588.50

Mink 620 pelts @ 8.00 . . 4,960.00

Beaver . . . 175 pelts @ 25.00 . . 4,375.00

Raccoon . . . 75 pelts @ 3.50 . . 262.50

14,186.00

Waterfowl23,600 items @ 0.50 11,800.00

Total \$124,510.00

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Fish	394,098 pounds @ \$0.25	\$98,524.00
Trout		
Muskete	3,059 pelts @ 1.50	\$4,588.50
Mink	620 pelts @ 8.00	4,960.00
Beaver	175 pelts @ 25.00	4,375.00
Raccoon	75 pelts @ 3.50	262.50
		14,186.00
Waterfowl	23,600 items @ 0.50	11,800.00
Total		
		\$121,510.00

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general guide for reservoir placement:

1. Reservoirs are to be placed above a point where permanent stream flow occurs.
2. The drainage area to an individual reservoir is to average less than 10 square miles.
3. Sufficient coverage of the land area should be made to eliminate ordinary flood damage throughout the basin.
4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

Regarding a specific reservoir, the following points were assumed to be desirable:

1. A permanent or conservation pool is to be maintained for utility and recreational purposes.
2. Temporary flood storage is to be provided above the permanent pool level.
3. Temporary flood storage capacity should be provided for 2 to 3 inches of surface runoff from the drainage area.
4. The depth of temporary flood storage above the permanent pool should not exceed 10 feet.
5. Temporary flood storage will be released without manual control.
6. Temporary flood storage is to be depleted at a rate which will cause a minimum of stream flow below the reservoir without destroying desirable vegetation, or resulting in loss of recreational value on the area adjacent to the permanent conservation pool.

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AN EVALUATION OF SMALL UPLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

I. GENERAL APPROACH

II. SUMMARY OF FINDINGS

Effect of the System on Floods
Flood reduction Benefits
Recreational Benefits
Benefits in the Form of Increased Fish and Game Production
Other Benefits
Cost-Benefit Relations

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System to be Evaluated
Notation
General Physical, Hydrologic, and Hydraulic Relationships
Functional Design of Each Reservoir

IV. EVALUATION OF FLOOD REDUCTIONS BY THE RESERVOIR SYSTEM

Development of Tributary Hydrographs
Hydraulic Equivalent Reach Cross-Sections
Routing Flood Waves Through Stream Reaches
Reach Hydrographs and Reservoir Reduction Trends
Modification of Flood Reductions by Reservoirs for Average
Runoff Conditions

V. DETERMINATION OF AVERAGE ANNUAL FLOOD REDUCTION BENEFITS

VI. RECREATIONAL BENEFITS

VII. BENEFITS IN THE FORM OF INCREASED FISH AND GAME PRODUCTION

VIII. OTHER BENEFITS

IX. PRELIMINARY COST ESTIMATES

X. TABLES

XI. FIGURES

XII. BIBLIOGRAPHY

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AN EVALUATION OF SMALL UPLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

The objective of this evaluation is to determine quantitatively the flood control benefits associated with the placement of a large number of small headwaters reservoirs on the 3,939 square mile area of the Meramec Drainage Basin. The reservoirs would be placed above the point of permanent stream flow, at which location they would ordinarily receive the drainage from land areas of less than 10 square miles. The location would also place them at points where their installation would result in a minimum of damage to agricultural lands, transportation systems, and urban developments.

This investigation should be considered as one of a preliminary nature. The design and placement of reservoirs on the basin is purely functional and its use is intended for estimating purposes only. In other words, data as given relative to any one specific reservoir may vary appreciably from the actual conditions present on the site, and are simply the most probable estimate that could be made from materials at hand without an actual visitation to the site. The decision to install a system of reservoirs of the type considered would necessitate the specific location of reservoirs and the determination of detailed physical information on each site.

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There are two fundamental principles involved in flood control. First, the amount of runoff may be decreased, and second, the timing of runoff to, or within, the stream channel system may be controlled to reduce peaks of flood flow. Land programs decrease the amount of flood runoff by the abstraction of rainfall producing floods. Large storage reservoirs may be used to abstract all or a portion of flood runoff from specific land areas. Retarding basins may be used to modify the timing of runoff from specific land areas into larger channel systems. The channel systems may also be treated to govern the timing and to modify the flood waves passing through them.

The initiation of land programs to abstract flow from floods and to control excessive erosion and siltation is basic to the successful application of other flood control devices. In addition to the benefits secured from the application of a land program further protection from floods will in most cases be needed. The location and type of flood damages should govern the choice of additional measures. Where the damages in small basins are primarily agricultural, small retarding basins located in the headwaters may give the desired protection. Larger structures will be necessary to give more absolute protection to concentrations of large damageable values.

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I. GENERAL APPROACH

A total of 253 small reservoirs were theoretically placed on the Meramec Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 56 tributary watersheds of the Meramec Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin.

The modification of average flood flows by the reservoirs was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be credited.

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credited.

The type and distribution of water areas, or conservation pools, common to installation of the small reservoirs is such that they create a new resource for recreation and the production of wildlife. The addition of these benefits to those determined for flood control comprises the estimated value of the reservoir system.

Estimates of the cost of installation of the reservoirs, their maintenance, and the acquisition and control of properties necessary for their placement and management constitute the original and continuing cost of the benefits to be attained. The relation of costs to benefits determines the economic feasibility of the system.

In the general organization of this report the basic tables and figures have been appended in the order in which they are mentioned in the body of the report.

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Table 5. General organization of the report.
Table 6. General organization of the report.
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II. SUMMARY OF FINDINGS

Effect of the System on Floods

The location of small reservoirs, as an average, produces flood reductions of approximately 35 percent on the headwaters tributaries which drain areas from 50 to 125 square miles. The magnitude of this reduction becomes progressively less as the flood waves proceed to the lower portions of the basin. Thus, the estimated flood reduction on the main stem of the Meramec is approximately 20 percent.

Upon routing and combining flood waves on each of the Bourbeuse, Big, and Meramec Rivers, it became apparent that small retarding basins should not be placed on the lower portions of each watershed. These lower portions of each watershed are relatively narrow and, in the normal course of events, contribute but little to the flood peaks which tend to originate at points farther up the basin. Flood producing storms tend to be of fairly wide scope on the basin, and runoff from the lower reaches normally moves out of the lower areas before the main peak of the flood arrives. To retard this runoff with small reservoirs will, in general, cause its direct addition to the main crest of the flood wave from above. Reservoirs below mile 31.6 on the Bourbeuse River, 107.5 on the Meramec River, and 22.6 on the Big River were, therefore, eliminated from the evaluation. This leaves a total of 198 reservoirs upon which all flood reductions are subsequently based. Recreation lakes without retarding features could, however, be built in these lower portions of the basin near the St. Louis area without conflict to flood control.

II. SUMMARY OF FINDINGS

Effect of the System on Floods

The location of small reservoirs, as an average, produces flood reductions of approximately 35 percent on the headwaters tributaries which drain areas from 20 to 125 square miles. The magnitude of this reduction becomes progressively less as the flood waves proceed to the lower portions of the basin. Thus, the estimated flood reduction on the main stem of the Meramec is approximately 20 percent.

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Wide variation in the reductions which the reservoirs will effect on specific floods are anticipated. Maximum reductions will be made on intense runoff that comes as a single peak flood when the entire flood storage capacity of the reservoirs is available. When the reservoirs are retaining runoff from previous storms and are in the process of discharging it at the time of a subsequent storm, the peak runoff from this second storm may upon occasion be greater than it would be without the reservoir system. Fortunately, this event will be of infrequent occurrence and is most likely to take place in the early spring or late fall months during the dormant seasons.

The type of control common to a system of small reservoirs is well adapted to a basin in which the flood damages are predominantly agricultural. Since approximately 75 percent of the existing flood damages in the Meramec Basin are comprised of those to farm crops and lands, and approximately 80 percent of them occur during the growing season, May through September, the control secured by small retarding devices is particularly effective.

The storms that produce flood damage on the Meramec Basin vary in duration from several hours to a few days. On larger watersheds, such as the Mississippi River Basin, the damaging floods result from protracted storms of wide scope where runoff accumulates in the river drainage system over a much longer period. Retarding devices such as those considered on the Meramec Basin, wherein runoff is temporarily detained for only a few days, will have negligible effect on Mississippi River floods.

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Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$516,670 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,000, or 55 percent of the total now existing on the basin.

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Of the \$200,050 annual benefit assigned to the small reservoirs, \$111,150 is obtained on the basin above the location of land areas inundated by the proposed construction of three multiple-purpose dams by the War Department.

Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$5,000,000 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$10,000,000. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$28,000,000, or 75 percent of the total now existing on the basin.

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Of the \$200,000 annual benefit assigned to the small reservoirs,

\$11,150 is obtained on the basis above the location of land areas

inundated by the proposed construction of three multiple-purpose dams

by the War Department.

It is estimated that for only a few years, will have significant

benefits from these dams.

Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extension of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$124,510 per year. The amount of this increase is equivalent to \$628.34 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

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Fish 394,098 pounds @ \$0.25 \$98,524.00

Fur

Muskrats . . .	3,059 pelts	@ 1.50	. . .	\$4,588.50	
Mink	620 pelts	@ 8.00	. . .	4,960.00	
Beaver . . .	175 pelts	@ 25.00	. . .	4,375.00	
Raccoon . .	75 pelts	@ 3.50	. . .	262.50	
					14,186.00

Waterfowl23,600 items @ 0.50 11,800.00

Total \$124,510.00

Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extension of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$121,510 per year. The amount of this increase is equivalent to \$628.64 per reservoir, or \$11.67 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

The breakdown of increased fish and game production is as follows:

Fish	391,098 pounds @ \$0.25	\$98,254.00
For		
Muskrate	3,059 pairs @ 1.50	\$4,588.50
Mink	620 pairs @ 8.00	\$4,960.00
Beaver	175 pairs @ 25.00	\$4,375.00
Raccoon	75 pairs @ 3.50	\$262.50
		14,186.00
Waterfowl	23,600 items @ 0.50	11,800.00
Total		
		\$121,510.00

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general guide for reservoir placement:

1. Reservoirs are to be placed above a point where permanent stream flow occurs.
2. The drainage area to an individual reservoir is to average less than 10 square miles.
3. Sufficient coverage of the land area should be made to eliminate ordinary flood damage throughout the basin.
4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

Regarding a specific reservoir, the following points were assumed to be desirable:

1. A permanent or conservation pool is to be maintained for utility and recreational purposes.
2. Temporary flood storage is to be provided above the permanent pool level.
3. Temporary flood storage capacity should be provided for 2 to 3 inches of surface runoff from the drainage area.
4. The depth of temporary flood storage above the permanent pool should not exceed 10 feet.
5. Temporary flood storage will be released without manual control.
6. Temporary flood storage is to be depleted at a rate which will cause a minimum of stream flow below the reservoir without destroying desirable vegetation, or resulting in loss of recreational value on the area adjacent to the permanent conservation pool.

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general

guide for reservoir placement:

1. Reservoirs are to be placed above a point where permanent stream flow occurs.
2. The drainage area to an individual reservoir is to be to average less than 10 square miles.
3. Sufficient coverage of the land area should be made to eliminate ordinary flood damage throughout the basin.
4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

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AN EVALUATION OF SMALL UPLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

I. GENERAL APPROACH

II. SUMMARY OF FINDINGS

Effect of the System on Floods
Flood reduction Benefits
Recreational Benefits
Benefits in the Form of Increased Fish and Game Production
Other Benefits
Cost-Benefit Relations

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System to be Evaluated
Notation
General Physical, Hydrologic, and Hydraulic Relationships
Functional Design of Each Reservoir

IV. EVALUATION OF FLOOD REDUCTIONS BY THE RESERVOIR SYSTEM

Development of Tributary Hydrographs
Hydraulic Equivalent Reach Cross-Sections
Routing Flood Waves Through Stream Reaches
Reach Hydrographs and Reservoir Reduction Trends
Modification of Flood Reductions by Reservoirs for Average
Runoff Conditions

V. DETERMINATION OF AVERAGE ANNUAL FLOOD REDUCTION BENEFITS

VI. RECREATIONAL BENEFITS

VII. BENEFITS IN THE FORM OF INCREASED FISH AND GAME PRODUCTION

VIII. OTHER BENEFITS

IX. PRELIMINARY COST ESTIMATES

X. TABLES

XI. FIGURES

XII. BIBLIOGRAPHY

AN EVALUATION OF SMALL UPLAND RESERVOIRS FOR FLOOD CONTROL PURPOSES

I. GENERAL APPROACH

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AN EVALUATION OF SMALL UPLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

The objective of this evaluation is to determine quantitatively the flood control benefits associated with the placement of a large number of small headwaters reservoirs on the 3,939 square mile area of the Meramec Drainage Basin. The reservoirs would be placed above the point of permanent stream flow, at which location they would ordinarily receive the drainage from land areas of less than 10 square miles. The location would also place them at points where their installation would result in a minimum of damage to agricultural lands, transportation systems, and urban developments.

This investigation should be considered as one of a preliminary nature. The design and placement of reservoirs on the basin is purely functional and its use is intended for estimating purposes only. In other words, data as given relative to any one specific reservoir may vary appreciably from the actual conditions present on the site, and are simply the most probable estimate that could be made from materials at hand without an actual visitation to the site. The decision to install a system of reservoirs of the type considered would necessitate the specific location of reservoirs and the determination of detailed physical information on each site.

AN EVALUATION OF SMALL WETLAND RESERVOIRS
FOR FLOOD CONTROL PURPOSES

The objective of this evaluation is to determine quantitatively the flood control benefits associated with the placement of a large number of small headwater reservoirs on the 3,939 square mile area of the Meramec Drainage Basin. The reservoirs would be placed above the point of permanent stream flow, at which location they would ordinarily receive the drainage from land areas of less than 10 square miles. The location would also place them at points where their installation would result in a minimum of damage to agricultural lands, transportation systems, and urban developments.

This investigation should be considered as one of a preliminary nature. The design and placement of reservoirs on the basin is purely functional and its use is intended for estimating purposes only. In other words, data is given relative to any one specific reservoir may vary appreciably from the actual conditions present on the site, and are simply the most probable estimate that could be made from materials at hand without an actual visitation to the site. The decision to install a system of reservoirs of the type considered would necessitate the specific location of reservoirs and the determination of detailed physical information on each site.

There are two fundamental principles involved in flood control. First, the amount of runoff may be decreased, and second, the timing of runoff to, or within, the stream channel system may be controlled to reduce peaks of flood flow. Land programs decrease the amount of flood runoff by the abstraction of rainfall producing floods. Large storage reservoirs may be used to abstract all or a portion of flood runoff from specific land areas. Retarding basins may be used to modify the timing of runoff from specific land areas into larger channel systems. The channel systems may also be treated to govern the timing and to modify the flood waves passing through them.

The initiation of land programs to abstract flow from floods and to control excessive erosion and siltation is basic to the successful application of other flood control devices. In addition to the benefits secured from the application of a land program further protection from floods will in most cases be needed. The location and type of flood damages should govern the choice of additional measures. Where the damages in small basins are primarily agricultural, small retarding basins located in the headwaters may give the desired protection. Larger structures will be necessary to give more absolute protection to concentrations of large damageable values.

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I. GENERAL APPROACH

A total of 253 small reservoirs were theoretically placed on the Meramec Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 56 tributary watersheds of the Meramec Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin.

The modification of average flood flows by the reservoirs was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be credited.

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was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be

credited.

The type and distribution of water areas, or conservation pools, common to installation of the small reservoirs is such that they create a new resource for recreation and the production of wildlife. The addition of these benefits to those determined for flood control comprises the estimated value of the reservoir system.

Estimates of the cost of installation of the reservoirs, their maintenance, and the acquisition and control of properties necessary for their placement and management constitute the original and continuing cost of the benefits to be attained. The relation of costs to benefits determines the economic feasibility of the system.

In the general organization of this report the basic tables and figures have been appended in the order in which they are mentioned in the body of the report.

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In the general organization of this report the basic tables and figures have been appended in the order in which they are mentioned in the body of the report.

II. SUMMARY OF FINDINGS

Effect of the System on Floods

The location of small reservoirs, as an average, produces flood reductions of approximately 35 percent on the headwaters tributaries which drain areas from 50 to 125 square miles. The magnitude of this reduction becomes progressively less as the flood waves proceed to the lower portions of the basin. Thus, the estimated flood reduction on the main stem of the Meramec is approximately 20 percent.

Upon routing and combining flood waves on each of the Bourbeuse, Big, and Meramec Rivers, it became apparent that small retarding basins should not be placed on the lower portions of each watershed. These lower portions of each watershed are relatively narrow and, in the normal course of events, contribute but little to the flood peaks which tend to originate at points farther up the basin. Flood producing storms tend to be of fairly wide scope on the basin, and runoff from the lower reaches normally moves out of the lower areas before the main peak of the flood arrives. To retard this runoff with small reservoirs will, in general, cause its direct addition to the main crest of the flood wave from above. Reservoirs below mile 31.6 on the Bourbeuse River, 107.5 on the Meramec River, and 22.6 on the Big River were, therefore, eliminated from the evaluation. This leaves a total of 198 reservoirs upon which all flood reductions are subsequently based. Recreation lakes without retarding features could, however, be built in these lower portions of the basin near the St. Louis area without conflict to flood control.

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Wide variation in the reductions which the reservoirs will effect on specific floods are anticipated. Maximum reductions will be made on intense runoff that comes as a single peak flood when the entire flood storage capacity of the reservoirs is available. When the reservoirs are retaining runoff from previous storms and are in the process of discharging it at the time of a subsequent storm, the peak runoff from this second storm may upon occasion be greater than it would be without the reservoir system. Fortunately, this event will be of infrequent occurrence and is most likely to take place in the early spring or late fall months during the dormant seasons.

The type of control common to a system of small reservoirs is well adapted to a basin in which the flood damages are predominantly agricultural. Since approximately 75 percent of the existing flood damages in the Meramec Basin are comprised of those to farm crops and lands, and approximately 80 percent of them occur during the growing season, May through September, the control secured by small retarding devices is particularly effective.

The storms that produce flood damage on the Meramec Basin vary in duration from several hours to a few days. On larger watersheds, such as the Mississippi River Basin, the damaging floods result from protracted storms of wide scope where runoff accumulates in the river drainage system over a much longer period. Retarding devices such as those considered on the Meramec Basin, wherein runoff is temporarily detained for only a few days, will have negligible effect on Mississippi River floods.

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Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$516,670 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,000, or 55 percent of the total now existing on the basin.

In applying increasingly rigid control measures to eliminate flood damages, the law of diminishing returns is operative. Thus, a greater benefit is secured by the first unit reduction than for succeeding equal unit reductions in floods. Since considerable time would necessarily elapse before the land program could be installed and become fully effective, the benefits directly ascribable to the reservoirs were evaluated by considering the land program to be 50 percent effective and eliminating farm ponds from the calculation. This method appears to be equitable and yields a flood control benefit of \$200,050 annually which is directly attributable to the reservoir system.

Of the \$200,050 annual benefit assigned to the small reservoirs, \$111,150 is obtained on the basin above the location of land areas inundated by the proposed construction of three multiple-purpose dams by the War Department.

Flood Reduction Benefits

Flood damages on the Metamora Basin are estimated at \$216,070 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

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Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extension of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$124,510 per year. The amount of this increase is equivalent to \$628.94 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

The breakdown of increased fish and game production is as follows:

Fish	394,098 pounds @ \$0.25	\$98,524.00
Fur		
Muskrats . . .	3,059 pelts @ 1.50 . .	\$4,588.50
Mink	620 pelts @ 8.00 . .	4,960.00
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Waterfowl	23,600 items @ 0.50	<u>11,800.00</u>
Total		\$124,510.00

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III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general guide for reservoir placement:

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4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

Regarding a specific reservoir, the following points were assumed to be desirable:

1. A permanent or conservation pool is to be maintained for utility and recreational purposes.
2. Temporary flood storage is to be provided above the permanent pool level.
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The System to be Evaluated
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X. TABLES

XI. FIGURES

XII. BIBLIOGRAPHY

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There are two fundamental principles involved in flood control. First, the amount of runoff may be decreased, and second, the timing of runoff to, or within, the stream channel system may be controlled to reduce peaks of flood flow. Land programs decrease the amount of flood runoff by the abstraction of rainfall producing floods. Large storage reservoirs may be used to abstract all or a portion of flood runoff from specific land areas. Retarding basins may be used to modify the timing of runoff from specific land areas into larger channel systems. The channel systems may also be treated to govern the timing and to modify the flood waves passing through them.

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I. GENERAL APPROACH

A total of 253 small reservoirs were theoretically placed on the Meramec Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 56 tributary watersheds of the Meramec Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin.

The modification of average flood flows by the reservoirs was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be credited.

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A total of 253 small reservoirs were theoretically placed on the Kermanshah Basin for evaluation purposes. This orientation of reservoirs was such that they received the drainage from slightly more than half the headwaters area making up the flow to the main stream system.

Physical data pertaining to the description of each reservoir were secured through the projection of general relationships developed on sample reservoir sites.

Hydrographs of runoff were developed on elemental land areas throughout the basin. The elemental areas used for this purpose coincided with the drainage areas to reservoir sites, and runoff hydrographs were derived as they would occur both without and with the reservoirs.

The hydrographs of runoff from the small elemental land areas were combined to represent graphs of runoff as they would occur without and with reservoirs on 50 tributary watersheds of the Kermanshah Basin. These tributary hydrographs were subsequently routed through the channels of the main drainage system to develop a regimen of flood flows at points throughout the basin.

The modification of average flood flows by the reservoirs was used as the basis for making a quantitative estimate of annual flood reduction benefits with which the system may be

credited.

The type and distribution of water areas, or conservation pools, common to installation of the small reservoirs is such that they create a new resource for recreation and the production of wildlife. The addition of these benefits to those determined for flood control comprises the estimated value of the reservoir system.

Estimates of the cost of installation of the reservoirs, their maintenance, and the acquisition and control of properties necessary for their placement and management constitute the original and continuing cost of the benefits to be attained. The relation of costs to benefits determines the economic feasibility of the system.

In the general organization of this report the basic tables and figures have been appended in the order in which they are mentioned in the body of the report.

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II. SUMMARY OF FINDINGS

Effect of the System on Floods

The location of small reservoirs, as an average, produces flood reductions of approximately 35 percent on the headwaters tributaries which drain areas from 50 to 125 square miles. The magnitude of this reduction becomes progressively less as the flood waves proceed to the lower portions of the basin. Thus, the estimated flood reduction on the main stem of the Meramec is approximately 20 percent.

Upon routing and combining flood waves on each of the Bourbeuse, Big, and Meramec Rivers, it became apparent that small retarding basins should not be placed on the lower portions of each watershed. These lower portions of each watershed are relatively narrow and, in the normal course of events, contribute but little to the flood peaks which tend to originate at points farther up the basin. Flood producing storms tend to be of fairly wide scope on the basin, and runoff from the lower reaches normally moves out of the lower areas before the main peak of the flood arrives. To retard this runoff with small reservoirs will, in general, cause its direct addition to the main crest of the flood wave from above. Reservoirs below mile 31.6 on the Bourbeuse River, 107.5 on the Meramec River, and 22.6 on the Big River were, therefore, eliminated from the evaluation. This leaves a total of 198 reservoirs upon which all flood reductions are subsequently based. Recreation lakes without retarding features could, however, be built in these lower portions of the basin near the St. Louis area without conflict to flood control.

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near the St. Louis area without conflict to flood control.

Wide variation in the reductions which the reservoirs will effect on specific floods are anticipated. Maximum reductions will be made on intense runoff that comes as a single peak flood when the entire flood storage capacity of the reservoirs is available. When the reservoirs are retaining runoff from previous storms and are in the process of discharging it at the time of a subsequent storm, the peak runoff from this second storm may upon occasion be greater than it would be without the reservoir system. Fortunately, this event will be of infrequent occurrence and is most likely to take place in the early spring or late fall months during the dormant seasons.

The type of control common to a system of small reservoirs is well adapted to a basin in which the flood damages are predominantly agricultural. Since approximately 75 percent of the existing flood damages in the Meramec Basin are comprised of those to farm crops and lands, and approximately 80 percent of them occur during the growing season, May through September, the control secured by small retarding devices is particularly effective.

The storms that produce flood damage on the Meramec Basin vary in duration from several hours to a few days. On larger watersheds, such as the Mississippi River Basin, the damaging floods result from protracted storms of wide scope where runoff accumulates in the river drainage system over a much longer period. Retarding devices such as those considered on the Meramec Basin, wherein runoff is temporarily detained for only a few days, will have negligible effect on Mississippi River floods.

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Mississippi River floods.

Flood Reduction Benefits

Flood damages on the Meramec Basin are estimated at \$516,670 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,000, or 55 percent of the total now existing on the basin.

In applying increasingly rigid control measures to eliminate flood damages, the law of diminishing returns is operative. Thus, a greater benefit is secured by the first unit reduction than for succeeding equal unit reductions in floods. Since considerable time would necessarily elapse before the land program could be installed and become fully effective, the benefits directly ascribable to the reservoirs were evaluated by considering the land program to be 50 percent effective and eliminating farm ponds from the calculation. This method appears to be equitable and yields a flood control benefit of \$200,050 annually which is directly attributable to the reservoir system.

Of the \$200,050 annual benefit assigned to the small reservoirs, \$111,150 is obtained on the basin above the location of land areas inundated by the proposed construction of three multiple-purpose dams by the War Department.

Flood Reduction Benefits

Flood damages on the Kalamazoo Basin are estimated at \$216,650 annually. Of this annual total, 75 percent is damage to crops and lands in the flood plain.

The comprehensive land program planned for the basin will reduce annual damages by \$109,160. When the system of 198 small reservoirs is superimposed on the land program, the annual combined flood reduction benefit is estimated at \$284,900, or 52 percent of the total now existing on the basin.

In applying increasingly rigid control measures to eliminate flood damages, the law of diminishing returns is operative. Thus, a greater benefit is secured by the first unit reduction than for succeeding equal unit reductions in floods. Since considerable time would necessarily elapse before the land program could be installed and become fully effective, the benefits directly attributable to the reservoirs were evaluated by considering the land program to be 50 percent effective and eliminating farm ponds from the calculation. This method appears to be equitable and yields a flood control benefit of \$200,050 annually which is directly attributable to the reservoir system.

Of the \$200,050 annual benefit assigned to the small reservoirs, \$111,150 is obtained on the basis above the location of land areas inundated by the proposed construction of three multiple-purpose dams by the War Department.

Benefits in the Form of Increased Fish and Game Production

The increased harvest of wildlife through the extention of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$124,510 per year. The amount of this increase is equivalent to \$628.84 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

The breakdown of increased fish and game production is as follows:

Fish 394,098 pounds @ \$0.25 \$98,524.00

Fur

Muskrate . . 3,059 pelts @ 1.50 . . \$4,588.50

Mink 620 pelts @ 8.00 . . 4,960.00

Beaver . . . 175 pelts @ 25.00 . . 4,375.00

Raccoon . . . 75 pelts @ 3.50 . . 262.50

14,186.00

Waterfowl 23,600 items @ 0.50 11,800.00

Total \$124,510.00

Benefits in the form of Increased Fish and Game Production

The increased harvest of wildlife through the extension of aquatic habitats and the stream improvement resulting from the installation of 198 reservoirs is conservatively estimated at \$125,520 per year. The amount of this increase is equivalent to \$236.04 per reservoir, or \$11.87 per water-acre. On a per acre basis the value of this wildlife harvest exceeds the present crop production which averages \$8.90 per acre per year on similar headwaters flood plain areas.

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Total	11,800.00
Waterfowl	23,600 items @ 0.50
	11,800.00
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Raccoon	75 pelts @ 3.50
	262.50
Beaver	175 pelts @ 25.00
	4,375.00
Mink	620 pelts @ 8.00
	4,960.00
Muskats	3,059 pelts @ 1.50
	4,588.50
For	
Plan	391,098 pounds @ \$0.25
	97,774.50

III. DESCRIPTION AND FUNCTIONAL DESIGN OF RESERVOIRS

The System To Be Evaluated

The following points were outlined to serve as a general guide for reservoir placement:

1. Reservoirs are to be placed above a point where permanent stream flow occurs.
2. The drainage area to an individual reservoir is to average less than 10 square miles.
3. Sufficient coverage of the land area should be made to eliminate ordinary flood damage throughout the basin.
4. No two reservoirs are to be placed in series. Thus, each reservoir would be an entity, and not be dependent upon the function or failure of any other reservoir.

Regarding a specific reservoir, the following points were assumed to be desirable:

1. A permanent or conservation pool is to be maintained for utility and recreational purposes.
2. Temporary flood storage is to be provided above the permanent pool level.
3. Temporary flood storage capacity should be provided for 2 to 3 inches of surface runoff from the drainage area.
4. The depth of temporary flood storage above the permanent pool should not exceed 10 feet.
5. Temporary flood storage will be released without manual control.
6. Temporary flood storage is to be depleted at a rate which will cause a minimum of stream flow below the reservoir without destroying desirable vegetation, or resulting in loss of recreational value on the area adjacent to the permanent conservation pool.

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